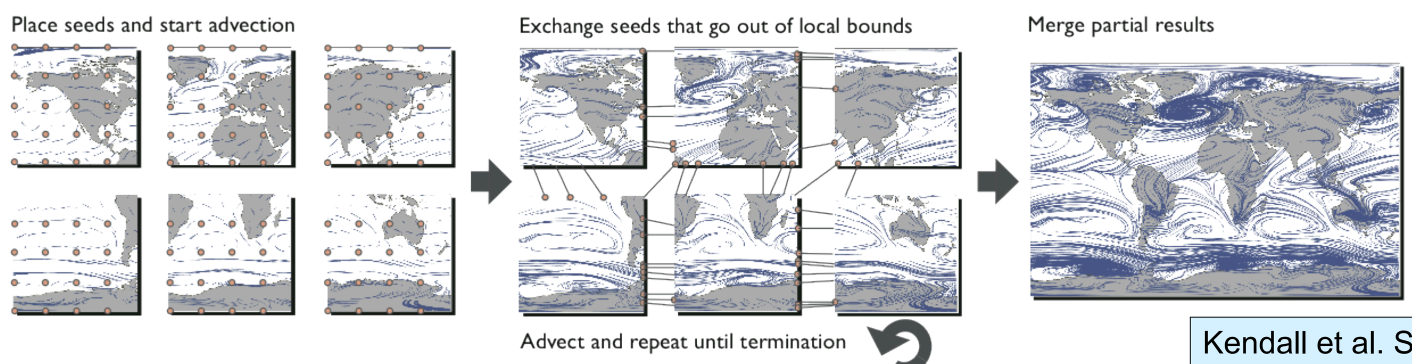
Time-Varying Flow Analysis and Visualization for Climate Science

Scalable Computation of Field Lines and Surfaces

The starting point of all flow analysis is particle advection.

Streamlines and Pathlines

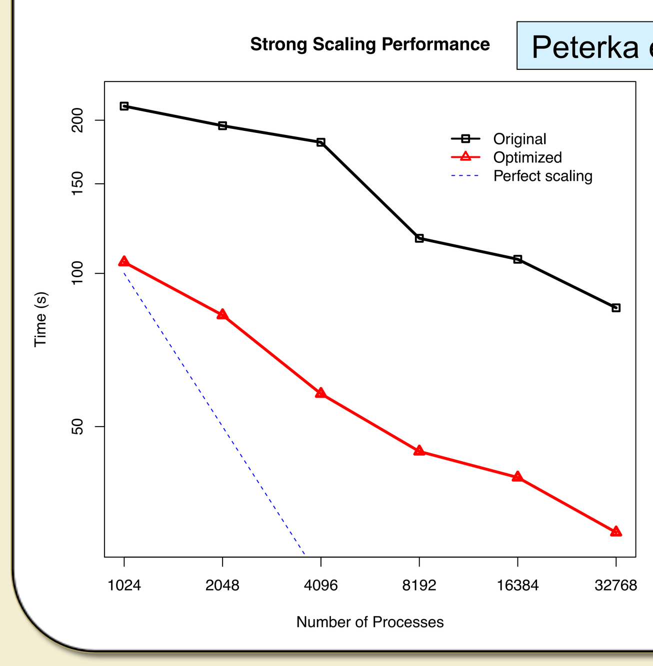
Particle trajectories are connected into curves.



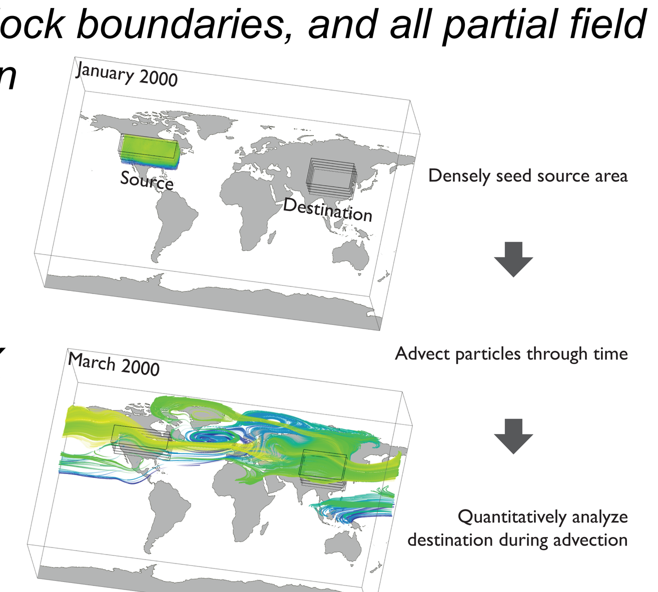
Kendall et al. SC11

In situ field line tracing is parallelized using spatial domain decomposition. Particles are initialized in subdomains (blocks) and then advected through the flow field. Particles are exchanged when crossing block boundaries, and all partial field lines are merged when particles finish advection

Peterka et al. IMUDI '12



Strong scaling performance time shows 3X improvement over previously published results.

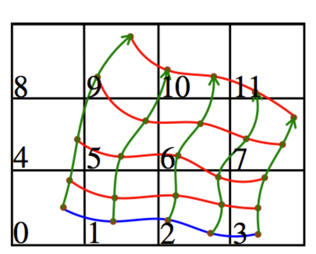


Teleconnections can be derived from correlations in source and destination of field lines.

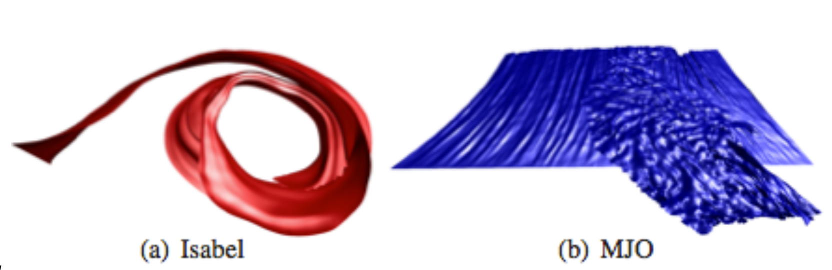
Stream Surfaces

Lu et al. SC14

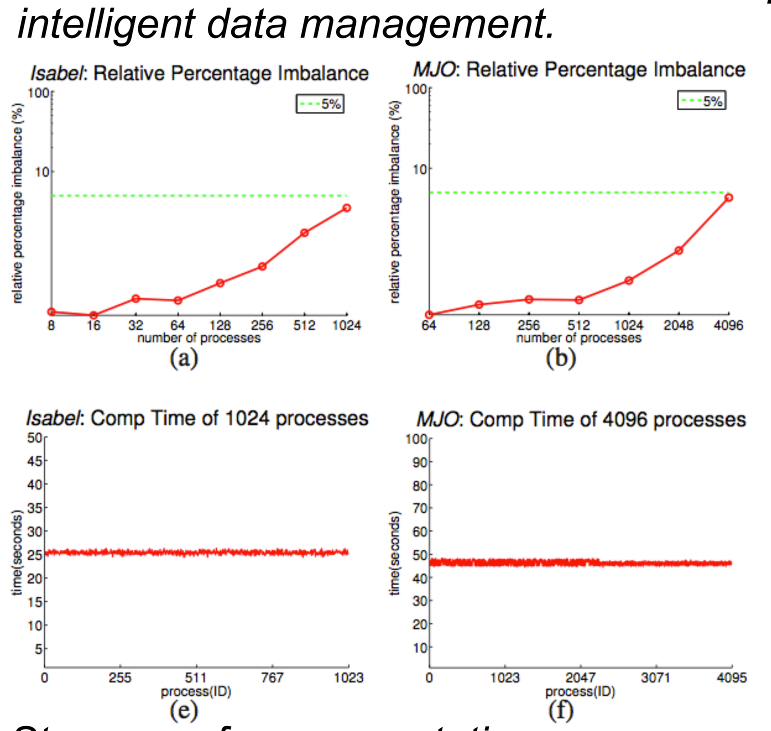
Field lines are connected into surfaces.



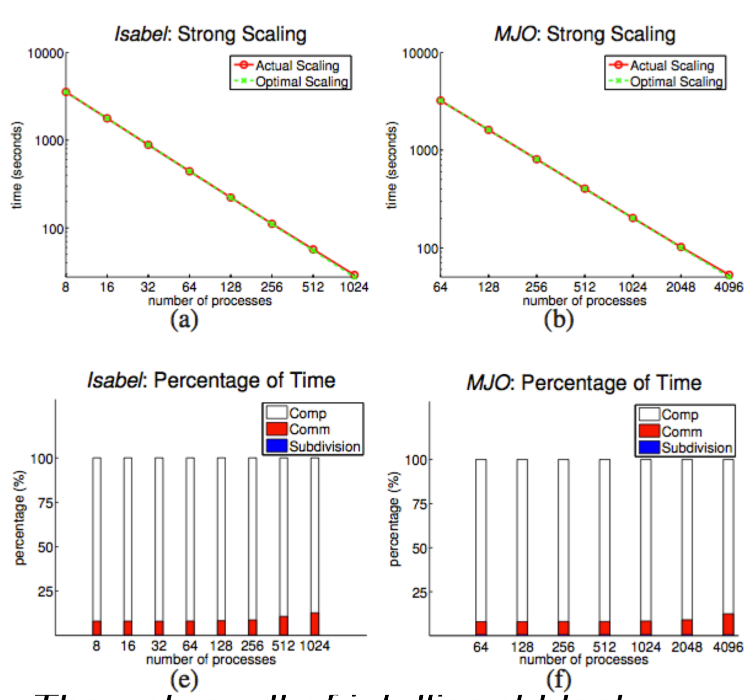
Stream surface integration repeatedly accesses the same blocks, requiring intelligent data management.



Examples of stream surfaces of hurricane Isabel and the Madden-Julian Oscillation.



Stream surface computation can cause severe load imbalance. Our work-stealing algorithm had < 5% imbalance at scale.



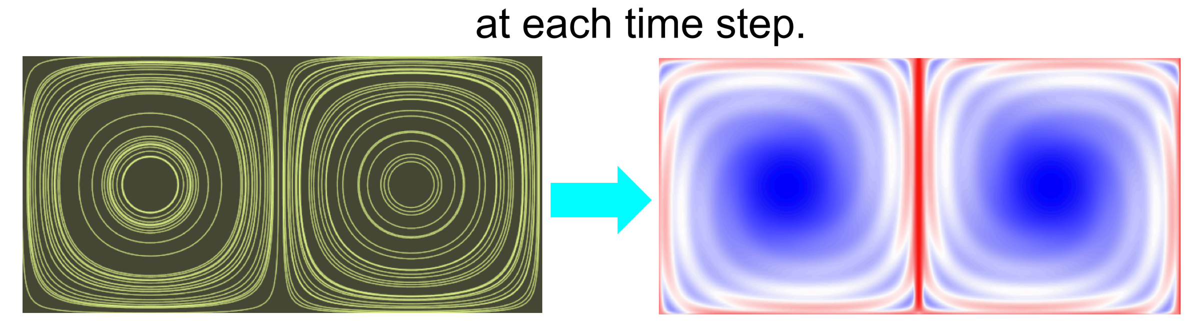
The net result of intelligent block management and dynamic load balancing is near-ideal strong scaling.

LaGrangian Coherent Structures

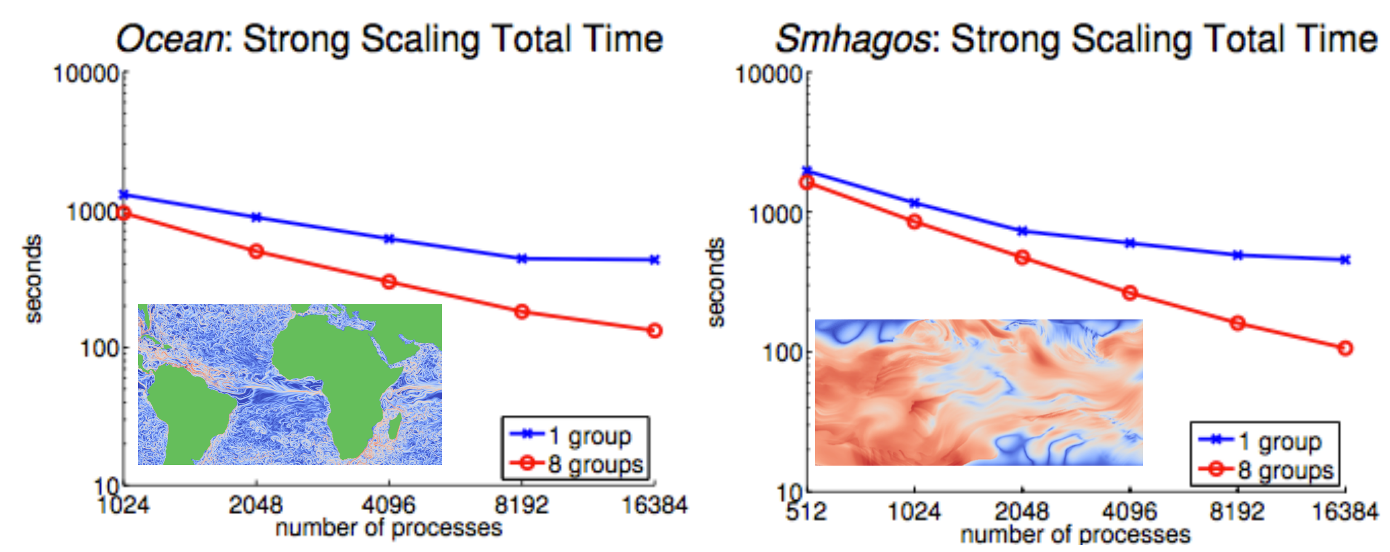
The divergence in pathlines can segment flow structures.

Scalable Computation of Deterministic FTLE

The Finite-Time Lyapunov Exponent (FTLE) is computed from pathlines seeded at each time step.



Example flow field (left) and resulting FTLE field (right). (red=diverging flow, blue = converging flow)

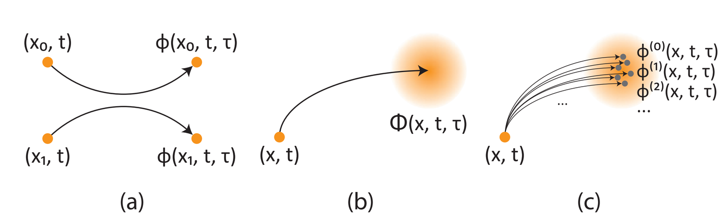


Left: particle tracing of 288 million particles over 36 time steps in a 3600x2400x40 eddy resolving dataset. Right: 62 million particles over 50 time steps in a 2699x599x27 climate model of the Indian and Pacific oceans. Time includes I/O.

Nouanesengsy et al. SC12

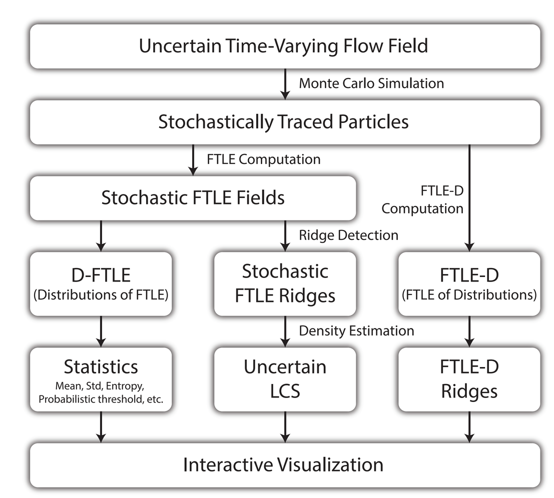
Definition of Stochastic FTLE

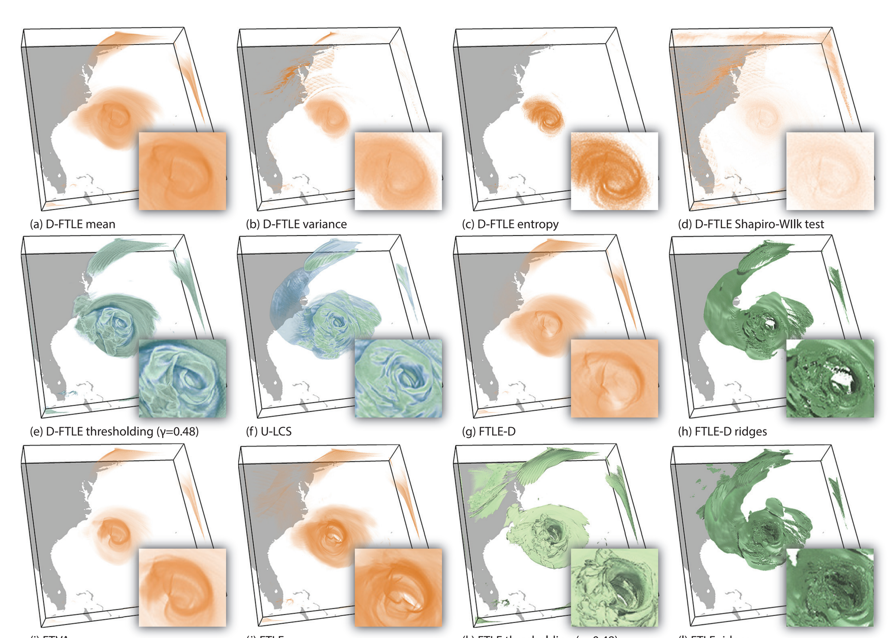
Quantities such as FTLE and features such as Lagrangian Coherent Structures (LCS) need to be redefined for stochastic flows.



A deterministic flow map (a) records the end point of each field line. A stochastic flow map (b) is computed by tracing many particles (c) in an uncertain vector field.

Analysis pipeline: Many Monte Carlo simulation runs trace densely seed particles stochastically. Uncertain FTLE and LCS are computed and interactively visualized.





Visualization of uncertain (a-j) and deterministic (k-l) hurricane Isabel data. Orange color denotes uncertain FTLE metrics, and green shows uncertain LCS metrics (e.g., ridge surfaces).

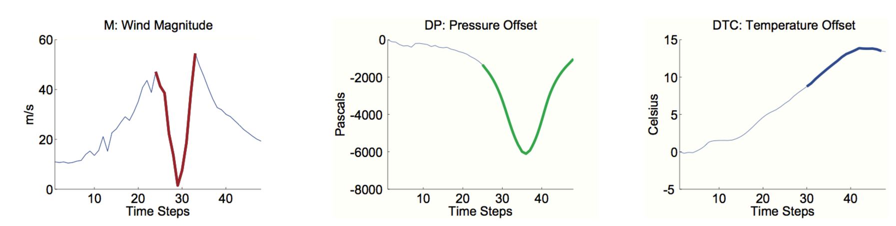
Guo et al. Pacific Vis '16

Information Theoretic Feature Detection

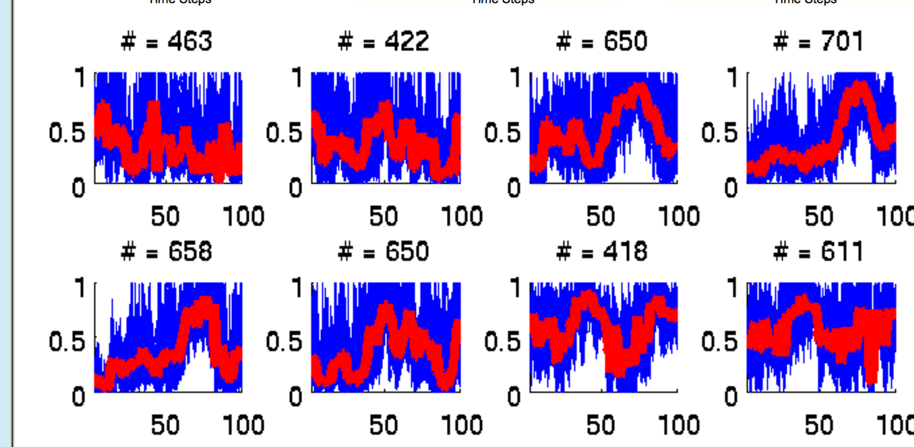
Data distribution statistics can also classify features.

Time Activity Curves

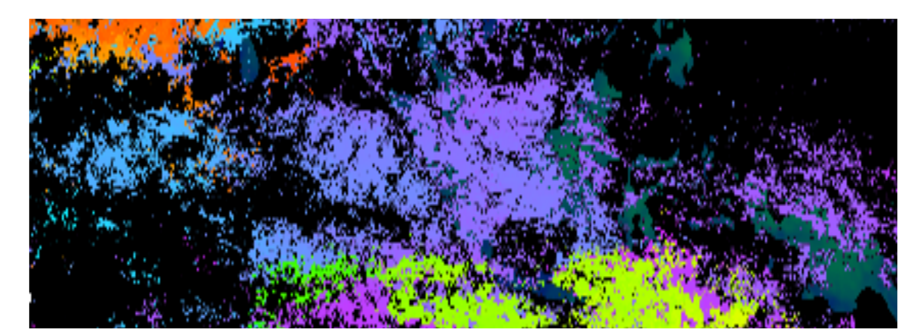
Temporal summarization helps scientists understand underlying time series in climate models.



Trends are identified by distinct signatures in their time series.



We developed a robust distance metric, the time activity curve (TAC) to compare the time series in different spatial regions. The distance metric allows us to cluster time series into a small number of trend types.

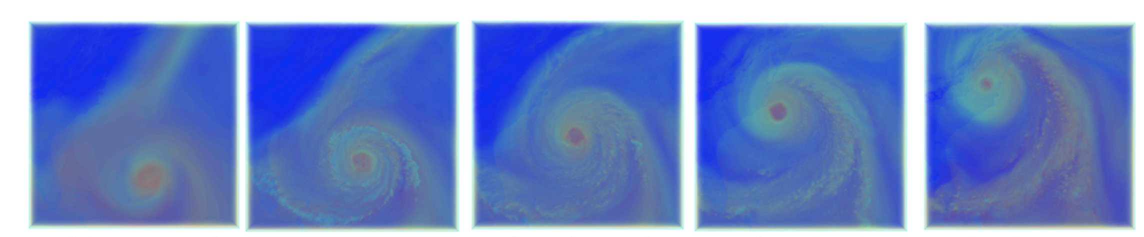


This distance field allows us to create novel visualizations of multivariate temporal events, such as the clustering of TACs in the Madden-Julian Oscillation (data courtesy Ruby Leung, PNNL).

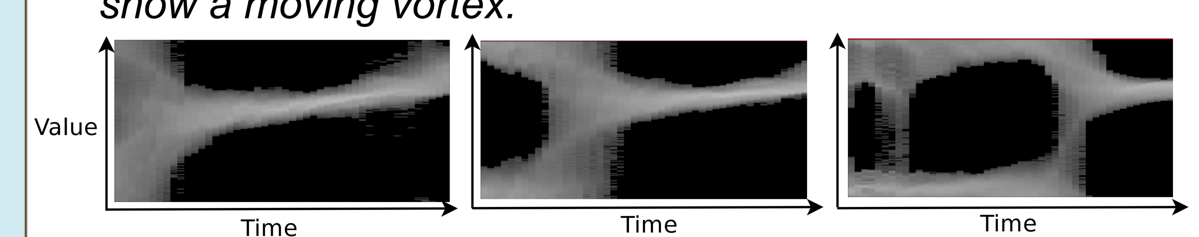
Lee et al. TVCG'09

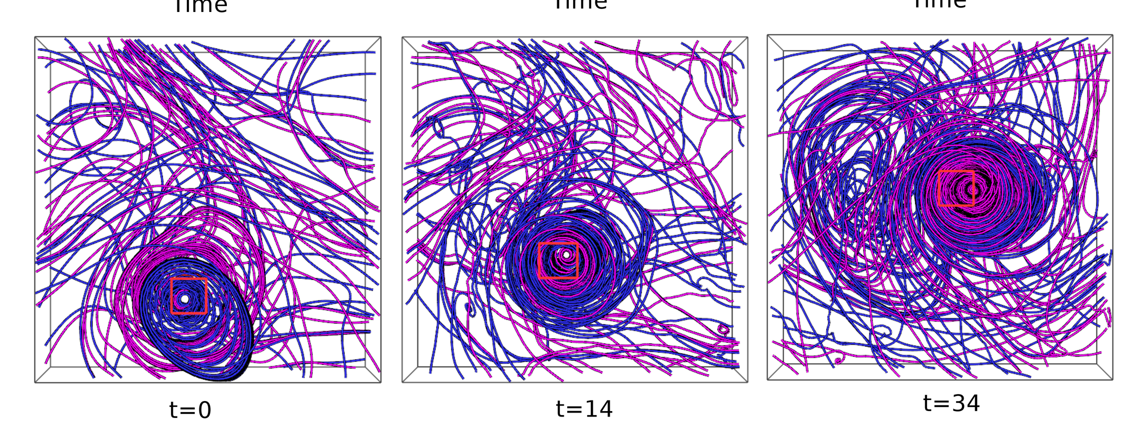
Time Histograms

Time histograms computed at block levels can serve as visual signatures of a feature's behavior over space and time.



Above: time steps from the hurricane Isabel simulation show a moving vortex.





A uniformly spread histogram (a bright vertical strip on a time histogram) indicates a vortex or turbulent region. Bands in the time histogram of a block signify the duration that the vortex is in the block. Users can quickly scan various time histograms to narrow down blocks where the vortex appears.

Three block-level time histograms (center row) computed from the wind velocity and the corresponding blocks (highlighted by red boxes in the bottom row). The time histograms clearly indicate the hurricane's presence in three different time steps.

Chaudhuri et al. LDAV '12

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